THE WEIGHT OF THE NORMAL HEART IN ADULT MALES*

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In 1936 an anthropometric survey of individuals coming to autopsy in this laboratory was inaugurated, the basic data consisting of linear and circumferential body measurements and organ weights. The general purpose of this study was to determine whether definite disease entities could be correlated with differences in physical constitution, but the specific problem under consideration was the question of body type as related to cardiovascular disease. Previously, Pearl and Ciocco[6] and Ciocco[3] had found that cardiacs and non-cardiacs differed significantly with respect to physical constitution, as determined by measurements taken on the living individual. It seemed possible that the more extensive anthropometric observations obtainable on autopsy material might enable us to amplify previous conclusions regarding the relationship between physical constitution and disease. In this connection, a review of the data already available in the departmental protocols was made in order to define the limits of variability of the weight of the normal heart and the factors related to such variability. This preliminary survey forms the basis of the present report.

The weight of the normal heart has received comparatively little attention from earlier investigators. Bardeen,[2] summarizing data collected by several different observers, concluded that at all ages except at and immediately after birth the relation of heart weight to body weight is approximately 0.55 per cent in males, while in females the heart is slightly lighter, the relation to body weight being 0.53 per cent. The earliest biometric survey of heart weight was made in 1904 by Greenwood,[4] who found the average weight of the healthy heart in 699 adult males of from 25 to 55 years of age to be 345 grams. He noted a significant but very low positive correlation between heart weight and age, and concluded that the average healthy heart gains about 10 grams in 10 years, the regression equation being 305+1.0 (age). However, reasoning that "the healthy heart is on the average much smaller than the heart in

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disease, and that sickness on the average increases consistently with age," Greenwood was inclined to place little emphasis on the general idea that the adult heart increases very sensibly with age alone. A later study by Greenwood and Brown[5] extended the earlier report. This study was based upon a rigorously selected group of 78 males aged from 25 to 55. Individuals with wasting disease, such as carcinoma or tuberculosis, with demonstrable cardiac lesions, or those with syphilis were excluded. This group had an average heart weight of 371 grams, and an average age of 41.3 years. The results with reference to the relation between heart weight and age were not significantly different from the older values, and the view expressed at that time was not modified. This paper records the first statistical correlation between heart weight and body weight. The linear correlation coefficient between these two variables was $0.65 \pm .04$—a highly significant value. Later, Smith[10] also studied the question of heart weight as related to body weight and age. His study was based upon accident cases with and without operation, cases with acute or chronic appendicitis or with hernia, gynecological cases where death occurred from pulmonary embolism, pneumonia, or shock following operation. A large percentage of cases were diagnosed as carcinoma of the stomach, breast, colon, or sigmoid. Excluded were all cases with diseases known or believed to affect the weight of the heart, such as syphilis, pernicious anemia, arteriosclerosis, chronic nephritis, hypertension, exophthalmic goiter, bronchial asthma, etc. All cases with morphologically demonstrable lesions of the heart were also discarded, as were also all cases presenting signs or symptoms of cardiac decompensation and those in which the heart was enlarged without demonstrable cause. Body weight was derived by weighing the patients on admission to the clinic. If there was a marked difference between the weight on admission and the patient's stated normal weight, the latter was used. Smith's figures for the average heart weight were 294 grams in males and 250 grams in females. He concluded that heart weight did not increase with age and that the weight of the male heart in grams could be derived from the weight of the body in kilograms by multiplying the latter by the factor 4.3.

Material and methods

The current series in the Department of Pathology at the Yale University School of Medicine covers the period from 1917 to the present. The first

4000 autopsies in this series were reviewed,[9] and from them were selected those cases dying as a result of trauma or from an acute infection or other disease requiring hospitalization of not more than two weeks' duration. All cases with carcinoma were excluded as were also those with morphological evidence of cardiovascular disease. The investigation was further narrowed to include only the observations on males aged 20 and over. The small number of observations on males younger than 20 and on females in all age classes made it necessary to eliminate these groups from consideration. Finally, it was necessary to exclude a large number of cases satisfying all of the above criteria where one or more of the following measurements were not available in the autopsy protocol: age, body weight, body length, and heart weight. The resultant group upon which this report is based comprises 187 individuals whose deaths were due to the causes shown in Table 1. Only 14 individuals in the group were colored, and the remainder, or 92.5 per cent, were white.

TABLE 1

THE CAUSES OF DEATH OF 187 MALES AGED 20 AND OVER PRESENTING NO MORPHOLOGICAL EVIDENCE OF CARDIOVASCULAR DISEASE AT AUTOPSY

Traumatic		77
Fractured skull	41	
Gunshot wounds	9	
Fractured ribs	8	
Burns	2	
Other traumata, including fractures, hemoperitoneum, etc.	17	
Infections		63
Pneumonia	34	
Peritonitis	11	
Meningitis	6	
Other acute infections	12	
Poisoning		20
Brain tumor		9
Miscellaneous		18

No case was excluded simply because the recorded heart weight violated preconceived notions of the weight of the normal heart. Several hearts weighed more than 400 grams and, in fact, two exceeded 550 grams. Moreover, the original histological preparations of the myocardium were not reexamined to determine whether microscopic evidence of hypertrophy was present, since none of the hearts in the selected series was diagnosed as hypertrophied at the time the gross and microscopic preparations were originally reviewed by the staff. In addition, it should be emphasized that the total weight of the heart is under consideration, not the weight of any particular chamber. It is evident that ventricular or auricular hypertrophy may occur even though the total weight may fall well within the accepted limits of normal.

It is recognized that the heart consists of four different tissues, each of which contributes its portion to the total weight. These tissues are the subepicardial fat, the heart muscle, the connective tissue, and the vascular tree including the supra-cardiac portion of the aorta. No effort was made to distinguish among these elements. The routine procedure in this laboratory has been to remove the heart by severing the major vessels at the base and to weigh the organ after opening it in the usual fashion. The length of the supra-cardiac portion of the aorta left attached to the heart has not been standardized. Heart weight and body length have been recorded by the numerous prosectors associated with the department during the past 20 years, and the technical error is thus markedly influenced by the variable accuracy of these different observers. The accuracy of the weight of the cadaver has likewise varied with the interest and skill of those who have made these determinations during the past two decades. Recognizing these sources of error, tabulations were prepared, statistical constants were calculated, and relevant and collateral correlation coefficients were derived.

Some English authors[4, 5] have recorded heart weight in ounces rather than in grams. Where such observations are cited in this report, ounces have been changed to grams by the factor 31 grams equals one ounce. Pounds have likewise been translated into kilograms by equating 2.2 pounds to one kilogram.

Results

The results are indicated in a series of tables and charts (Tables 2 to 7; Figs. 1 and 2). Table 2 is a frequency distribution of the

TABLE 2

DISTRIBUTION FREQUENCY OF HEART WEIGHTS OF 187 ADULT MALES AGED 20 AND OVER

Weight in grams	*Frequency*	*Per cent*
200—249	2	1.1
250—299	17	9.1
300—349	63	33.7
350—399	58	31.0
400—449	30	16.0
450—499	13	7.0
500+	4	2.0
Total	187	100.0

observed heart weights, the mean for the entire group being 355.8 ± 4.5 grams, with a minimum of 210 grams and a maximum of 565 grams. A slight skew in the direction of higher values is shown in the table. On the basis of accepted statistical procedure, 95 per cent

TABLE 3

CONSTANTS CALCULATED FROM DATA ON 187 MALES AGED 20 TO 74

Variable	*Mean*		*Standard deviation*	*Coefficient of variation*
Age	44.1 ±0.9	yrs.	12.7	28.9
Heart weight	355.8 ±4.5	gms.	60.9	17.1
Body weight	68.6 ±0.8	kgs.	11.3	16.5
Body length	167.8 ±0.8	cms.	11.2	6.7
Surface area	1.76±0.01	sq. m.	0.16	9.3
Body-weight ratio	408 ±5.0		65.0	15.9
Body-weight ratio / Heart weight	1.17±0.01		0.18	15.3

of the observations are expected to fall within the limits of 234 and 478 grams (mean plus and minus twice the standard deviation).

The ages ranged from 20 to 74 years, with a mean of 44.1±0.9 (Table 3). A small but significant positive correlation (.2670) was observed between the values for heart weight and age (Table 4). When actually plotted, as in the scatter diagram (Fig. 1), the heart weights of individuals aged 60 and over fell, in general, below the

TABLE 4

CORRELATIONS CALCULATED FROM DATA ON 187 MALES AGED 20 TO 74

	*Total Correlations**			
	Heart weight	*Body weight*	*Body length*	*Age*
Heart weight	1	**.5866**	.1171	**.2670**
Body weight	**.5866**	1	**.3391**	.0723
Body length	.1171	**.3391**	1	−.1042
Age	**.2670**	.0723	−.1042	1
Surface area	**.5711**			
Body-weight ratio	**.4980**			

* Significant values are in bold-face.

straight line trend calculated on the basis of the entire group of 187 observations, suggesting that there is a retardation in the growth of the normal human heart after age 60. This, however, had no material effect on the correlation between age and heart weight, for when the older group was eliminated, and a new correlation coefficient based upon the 167 observations on individuals between 20 and 59 was calculated, the resulting coefficient (.2901) was greater but not significantly greater than that obtained with all of the 187 observations. The regression equation for heart weight and age was:

Estimated Heart Weight in Grams = 300 + 1.3 (Age)

The standard error of estimate was 58.9 grams. In this series, therefore, heart weight increased 13 grams for each 10 years of age. This compares with an increase of 10 grams per decade reported by Greenwood. It should be noted, also, that the effect of age on heart weight was not due to any common relationship existing between them and body weight. This is indicated by the first order partial correlation coefficient of .2783 between age and heart weight (Table 5), independent of the accompanying variation in body weight. This value is not significantly different from the zero order coefficient of .2670 between age and heart weight.

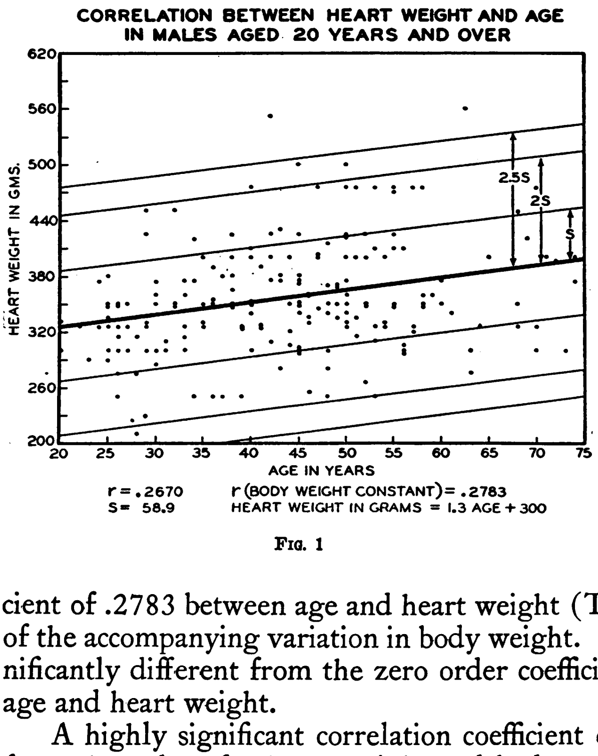

FIG. 1

A highly significant correlation coefficient of .5866 was derived from the values for heart weight and body weight, and the regression equation was:

Estimated Heart Weight in Grams = 140 + 3.2 (Body Weight in Kilograms) with a standard error of estimate of 49.5 grams (Fig. 2). Thus, heart weight increased 32 grams for each 10-kilogram increase in body weight. A heart weight-body weight correlation coefficient of similar magnitude and direction was previously reported by Greenwood. Here again the significant relationship observed between heart weight and body weight was not influenced by any common relationship existing between them and age, since the

TABLE 5

CORRELATIONS CALCULATED FROM DATA ON MALES AGED 20 TO 74

	r	r^2	S.D.
Total correlation—Age and heart weight	.2670	.071	58.9
Partial correlation—Age and heart weight with body weight constant	.2783	.077	
Total correlation—Body weight and heart weight	.5866	.344	49.5
Partial correlation—Body weight and heart weight with age constant	.5910	.349	
Multiple correlation—Body weight, age, and heart weight	.6287	.395	38.4
Multiple correlation—Body weight, age, height, and heart weight	.6118	.374	48.0

first order partial correlation coefficient, with age constant, was only .5910, essentially no different from the zero order coefficient of .5866 observed between heart weight and body weight.

A significant positive relationship was noted between body length and body weight, and this is in agreement with the observations of Pearson.[7] No significant relationship was discovered between body length and heart weight, between body weight and age, or between body length and age. The latter correlation coefficient constituted the only negative relationship between any two of the variables studied. This finding indicates a decrease in body length with increasing age, and is supported by the

CORRELATION BETWEEN HEART WEIGHT & BODY WEIGHT IN MALES AGED 20 YEARS AND OVER

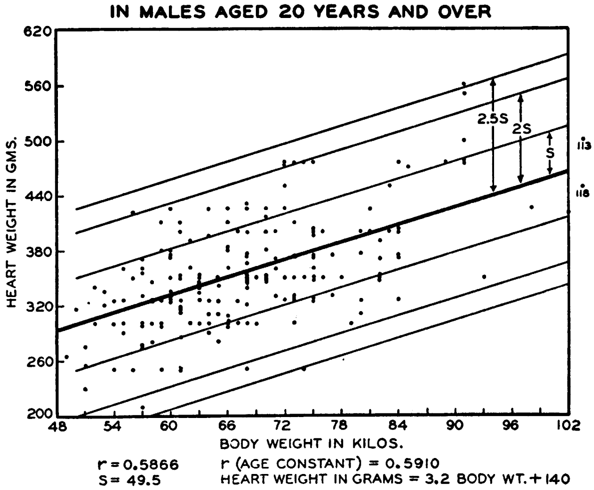

FIG. 2

observations of Powys.[8] This investigator studied the stature of criminals in New South Wales, and concluded that males reach their maximum stature at age 28, thereafter losing an average of .34 inches per 10 years.

Since age and body weight each significantly affected heart weight, but were not themselves related, a multiple correlation coefficient was calculated from these three variables. This proved to be the highest coefficient obtained, .6287. The multiple regression equation was:

Estimated Heart Weight in Grams = 1.1 (Age) + 3 (Body Weight in Kilograms) + 97.8 and the standard error of estimate was 38.4 grams. For convenience in calculating, the above equation has been simplified as follows:

Estimated Heart Weight in Grams = Age + 3 (Body Weight in Kilograms) + 100.

The use of this equation will give an estimated heart weight which in 95 per cent of normal cases should fall within the range of the observed heart weight plus or minus twice the standard error of estimate. For practical purposes, therefore, any heart weighing more than the estimated heart weight obtained by the use of this regression equation plus 77 grams is a hypertrophied heart.

It has previously been stated that height had no influence on heart weight. Since, however, height in association with body weight might presumably affect heart weight, two new variables were studied. These are surface area and body-weight ratio, both of which are derivatives of height and body weight. The values for surface area were obtained from the Dubois height-weight formula for surface area. The body-weight ratio values represent the weight in grams per centimeter of height and were obtained by dividing body weight in grams by height in centimeters. These two variables when correlated with heart weight gave significant positive coefficients, but in neither case was their relationship with heart weight as high as was that between body weight, exclusive of height, and heart weight (Table 5). Moreover, the multiple correlation coefficient between heart weight and height and body weight and age (.6118) was not as large as was the multiple coefficient of correlation between heart weight and body weight and age, exclusive of height (.6287). On this basis height does not appear significantly to influence heart weight, except in so far as height alone affects body weight.

When, however, the usual relationship between height and body weight is absent, height becomes a variable which can be taken into consideration in determining normal heart weight. It was observed in working with the data that the body-weight ratio (weight in grams per centimeter of height) was approximately equal to the heart weight. The value for body-weight ratio divided by heart weight was therefore derived for each of the individuals under review, and a distribution frequency table was prepared (Table 6). The result-

TABLE 6

DISTRIBUTION FREQUENCY OF BODY-WEIGHT RATIO DIVIDED BY HEART WEIGHT

B.W.R./H.W.	*Number*
0.8 – 0.9	21
1.0 – 1.1	80
1.2 – 1.3	60
1.4 – 1.5	18
1.6 – 1.7	5
1.8+	3

Mean = 1.17
S.D. = 0.18
Mean + 2 S.D. = 1.53
Mean – 2 S.D. = 0.81

ant value in most instances was greater than 0.8, and ranged from this as a minimum to 2.0 as a maximum, with a mean of 1.17, and a standard deviation of 0.18. The limits of 0.81 and 1.53 describe the range between the mean plus and minus twice the standard deviation. A value of less than 0.8 is thus probably derived from a different population of data, and such a value would therefore be interpreted as indicating cardiac hypertrophy. Similarly a value of more than 1.53 would indicate cardiac atrophy.

Discussion

In the group under review the average weight of the heart was 356 grams. This compares with an average of 321 grams reported by Aschoff[1] in a study of the hearts of 685 soldiers. Smith found the average adult male heart in his series to weigh 294 grams, while Greenwood in his first study found the average heart weight in adult males to be 345 grams. A later study by Greenwood and Brown gave the average adult male heart weight as 371 grams. The variability between these values is probably due to the selection of the material. The greatest difference is in the figures presented by Smith, but it should be recalled that this investigator included in his survey the hearts of individuals dying of malignant disease. It is not possible to determine from the published report to what extent this factor influenced the final result. Moreover, Smith eliminated from his original material all hearts that were "enlarged without demonstrable cause." In a study to determine the limits of the weight of the normal heart this procedure would appear to indicate *a priori* knowledge of the upper limit of normality.

There is a considerable difference of opinion concerning the effect of age on the weight of the adult heart. In the present survey heart weight varied significantly with age, but this relationship was not very great, since age alone accounted for only about 7 per cent of the variation in heart weight. It would appear at first glance that the demonstrated increasing heart weight with increasing age was not the result of age per se, but rather of a possible increasing incidence of hypertension in the older age groups, with resultant cardiac hypertrophy. An attempt was therefore made to determine whether hypertension was the factor involved.

It should be recalled in this connection that a majority of the patients in the survey came to autopsy after a traumatic death. It is not possible to ascertain the incidence of hypertension in the entire group, since blood pressures were not recorded on a great many of these violent deaths. The original material was selected without any regard to blood pressure but when the positive influence of age on heart weight was evidenced, the protocols were reviewed with

TABLE 7

BLOOD PRESSURE OF 187 MALES AGED 20 AND OVER WITH NO MORPHOLOGICAL EVIDENCE OF CARDIOVASCULAR DISEASE AT AUTOPSY

No recorded blood pressure in	115, or 61.5%
Recorded blood pressure in	72, or 38.5%
Of these, hypertension* occurred in	15, or 20.8%
These 15 died of	
Fractured skull	7
Pneumonia	4
Meningitis	2
Brain tumor	1
Postoperative	1

* Systolic pressure 140 mm. and over, or diastolic pressure 90 mm. and over.

the question of hypertension in mind. The blood-pressure records were available in only 72 or 38.5 per cent of the entire group of cases (Table 7). Hypertension, as determined by a systolic pressure of 140 mm. or more or by a diastolic pressure of 90 mm. or more, was present in 15 or 20.8 per cent of the 72. Death resulted from a fractured skull in 7 of these 15, from pneumonia in 4, meningitis in 2, and from brain tumor and postoperative complication in one each. It is entirely likely, although not known with certainty, that the hypertension in a certain proportion of these 15 was the direct result of the terminal disease. Only 9 of the 15 patients with hypertension exceeded 50 years of age. The mean heart weight for this group with hypertension was 365 grams, which is not significantly different from the mean heart weight for the entire group of 187 individuals. Moreover, the mean estimated heart weight for this group of 15 with hypertension, based upon the multiple regression equation determined from the observations on the entire group of 187 cases, was 353 grams which is not significantly different from the mean observed heart weight. From this it can be concluded that although hypertension rather than age may be the factor involved in the observed positive relationship between heart weight and age, it does not, at least in this group, exert a striking influence.

In this connection a review of other available data is of interest. In Aschoff's group of soldiers, the average heart weight of 235 individuals aged 20 to 29 was 311 grams, while 64 individuals aged 40 to 50 had the higher mean weight of 344 grams. Moreover, Greenwood's observations on 358 individuals aged 25 to 35 resulted in a mean heart weight of 369 grams, while in 403 individuals aged 45 to 55 the average heart weight was 422 grams. In neither of these reports is it possible to eliminate the factor of hypertension as the dominant influence rather than age alone.

Heart weight was very highly correlated with body weight, the resulting zero order correlation coefficient being .5866. This finding is in essential agreement with that of Greenwood and Brown, who reported a correlation coefficient between heart weight and body weight of .65. From our own data it appears that body weight contributes approximately 35 per cent to the variability of heart weight. Holding age constant did not materially increase the value for the correlation between body weight and heart weight, and it is thus evident that body weight irrespective of age is the important factor.

There was no significant correlation between body length and heart weight, but body length was significantly correlated with body weight. This is in agreement with the findings of Pearson. It is interesting to observe that the only negative correlation coefficient in the series was found to occur between age and body length. Although this value is not significant, it is apparent that body length decreases slightly with increasing age. Age alone had no appreciable influence on body weight, as is indicated by the insignificant correlation coefficient of .07.

It will be recalled that the individuals studied were divided into two major groups according to the cause of death. The first group consisted of 77 persons whose deaths were due directly to trauma, and the second group comprised 63 patients who died as the result of an acute infection. The mean values for age and heart weight of these two groups were compared. The mean age of the trauma group was 44.4±1.55 years, as compared with a mean age of 44.6±1.57 years in the infection group. The difference (0.2±2.2 years) between these two means is not significant. The mean heart weight in the trauma group was 364±7.7 grams as compared with a mean of 352±7.5 grams for the infection group. This difference (12±10.7 grams) is likewise not statistically significant. In this series, therefore, the age incidence and the heart weights of individuals dying of trauma were no different from those dying as the result of an acute infection. It thus does not appear that any edema of the cardiac musculature which might have been caused by the acute infectious diseases had any influence on the heart weight.

The autopsy protocols which had accumulated after the selection of the material upon which this paper is based were reviewed, and an additional group of cases satisfying the criteria previously discussed was selected. The group included 28 males, occurring in sequential order in the protocols, aged 20 years or more, with no cardiovascular disease at autopsy. The minimum heart weight was 285 grams and the maximum was 480 grams, with a mean of 375 grams. The estimated heart weight for this group, employing the previously described regression equation—Estimated Heart Weight in Grams=Age+3(Body Weight in Kilograms)+100—showed a minimum value of 300 grams, a maximum value of 460 grams, and a mean of 368 grams. There was no significant difference between the observed and the estimated mean heart weight in this group, and moreover in no case did the estimated heart weight exceed the observed value by more than 77 grams.

A second group of individuals with obvious cardiovascular disease and hypertrophied hearts was studied. This comprised 9 males aged 20 and over who had hearts weighing from a minimum of 470 grams to a maximum of 660 grams, the average being 571 grams. The estimated heart weight employing age and body weight in the above equation gave a minimum of 285 grams, a maximum of 410 grams, and an average of 348 grams. It is seen that the minimum, maximum, and mean observed values for heart weight in this group exceeded the corresponding estimated heart-weight value by more than 77 grams, or twice the standard error of estimate previously described. When actually put to test, therefore, the regression equation for estimating the weight of the normal heart appears to give values which fall well within the limits of the described error estimate.

It has already been noted that when the body weight per centimeter of height divided by the weight of the heart gives a value of less than 0.8, this result may be interpreted as indicating cardiac hypertrophy. The test of this hypothesis was put to the data on the 28 males with no cardiovascular disease and also on the 9 males with cardiovascular disease and hypertrophied hearts. In the first group the range of the body-weight ratio divided by the heart weight was from a minimum of 0.9 to a maximum of 1.7, with a mean of 1.14. None of these values was less than 0.9. In the second group of 9 individuals with cardiovascular disease, the body-weight ratio divided by the heart weight ranged from a minimum of 0.60 to a maximum of 0.85. In only one instance was the value greater than 0.8 and the mean for the entire group was 0.68. This is smaller than the mean of the 187 survey cases less twice the standard deviation. Actual test thus appears to demonstrate the validity of the hypothesis formulated above.

In conclusion, the following quotation from Greenwood and Brown's paper, published in 1913, is presented without further comment:

> The non-medical reader will perhaps wonder how it is that we think it worth while to deal with so few cases, and may object that the London Hospital is only one of a number of great medical charities and that the material from all of these should be pooled and treated as a whole. This would be so obviously the proper course were it practicable that we may be allowed to point out the difficulties in the way of its adoption. The effective absence of coordination between the medical schools, the diverse systems in

force and the contempt of statistical data which up to recent times characterized all but a minority of the hospital staffs, would render any individual attempt to deal with combined records a troublesome and possibly futile undertaking. We are not speaking without knowledge of the statistical systems in vogue at a large hospital when we say that the present state of affairs is unsatisfactory. Every year tons of paper and gallons of ink are devoted to recording the experiences, medical, surgical and pathological, of the great teaching institutions. An extremely small percentage of the results have any value at all, while even that residuum is not readily accessible. Comparatively little trouble and some expense would notably diminish the output of waste-paper and increase the production of valuable records.

Summary

1. A group of 187 males aged 20 years and over with no cardiovascular disease at autopsy, dying either from trauma or from an acute disease requiring not more than two weeks of hospitalization, was studied to determine the influence of age, height, and body weight upon the weight of the heart. The mean age for this group was 44.1 years and the average heart weight was 356 grams.

2. A slight but significant positive correlation of .2670 was found between age and heart weight. It was not possible to exclude entirely the influence of hypertension as a factor accounting for this significant correlation, but it appeared that if hypertension rather than age were the influential factor, it did not account for more than 7 per cent of the variability in observed heart weight.

3. Body weight and heart weight were significantly correlated in a positive direction. This was independent of age.

4. Surface area and body-weight ratio, both of which are derivatives of body weight and height, were both significantly correlated with heart weight, but at a lower level of significance than the correlation between heart weight and body weight alone. Height therefore did not appear to contribute materially to the variability in the weight of the heart.

5. The multiple correlation between heart weight and body weight and age was .6287. This gave the lowest standard error of estimate of any of the correlation coefficients determined. The corresponding multiple regression equation was: Estimated Heart Weight in Grams = Age + 3 (Body Weight in Kilograms) + 100. It was concluded that a diagnosis of cardiac hypertrophy was justified when the observed heart weight exceeded by more than 77 grams

the estimated heart weight derived by the use of this regression equation.

6. The weight in grams per centimeter of height divided by the heart weight gave a range of from 0.8 to 2.0 with a mean of 1.17 and a standard deviation of 0.18. A similarly derived value, it was estimated, which was less than 0.8, could be interpreted as indicating cardiac hypertrophy.

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